International Space Station U.S. GN&C Momentum Manager Controller Design for Shuttle Thermal Protection System Repair

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This paper describes the design of the ISS Momentum Manager controllers for the Orbiter Repair Maneuver (ORM) and Orbiter Tile Repair operations. Momentum Manager Controllers provide non-propulsive attitude control via CMGs. Non-propulsive control is required at the beginning and the middle of the ORM and at the tile repair position. This paper first reviews the design issues and requirements, then presents the design methodology, and concludes with analysis results that verify the design.

I. Introduction

For Space Shuttle Flight LF1, an on-orbit repair capability for the Shuttle's Thermal Protection System (TPS) was desired. The accepted solution was to perform the repair while the Shuttle is at the International Space Station (ISS). The repair would be done by an astronaut attached to the Space Station Robotic Manipulator System (SSRMS). The SSRMS does not have enough reach capability to reach potential repair sites with the Space Shuttle docked to the available docking ports. This is overcome by utilizing the Shuttle Robotic Manipulator System (SRMS). The SRMS grapples the Station while the Shuttle undocks from the ISS. The SRMS will then effectively flip the Shuttle upside down exposing the underside of the Shuttle to the reach space of the SSRMS while ISS maintains attitude control. This robotic operation is called the Orbiter Repair Maneuver (ORM). In order to make it more operationally feasible, an overnight park position happens midway through the maneuver.

The ISS should utilize its non-propulsive attitude control capability at Shuttle unberthing, Shuttle berthing, the ONP, and the final repair position. This paper describes the design and analysis of the controllers that were made to provide non-propulsive attitude control for these stages of the TPS repair.

II. Designs

The ISS provides non-propulsive attitude control via a linear control law called Momentum Manager. This control law is based on the design detailed in [1].

Momentum Manager Controller designs for use in the TPS repair operations have several design issues that all ISS Momentum Manager designs have as well as unique ones due to the repair operations. The following list captures general ISS momentum manager design goals:

- No steady state CMG desaturations (non-propulsive goal)
- Maintain attitude envelopes in startup and steady state
- Peak steady CMG momentum levels should allow for single CMG failure
- Minimize attitude variation and attitude rate

Design trades exist between all these mentioned goals and these trades are bounded by the vehicle angular dynamics of earth oriented orbiting spacecraft and expected aerodynamics torque loading. For a more detailed discussion see [1].

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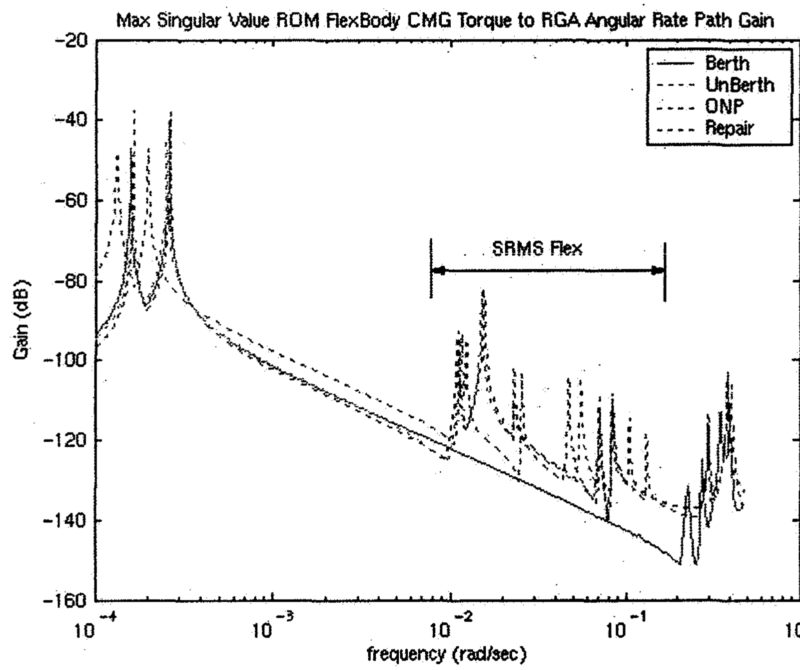
For TPS repair operations new design challenges exist. One being the SRMS dynamics, its flexible dynamics are located near the bandwidth of the standard MM designs (0.007 rad/sec). Figure 1 shows the SRMS flex dynamics that are added compared to the berth model which has no SRMS flex dynamics. The MM design should avoid unstable or poor interaction with the SRMS. This challenge is made more difficult due to the nonlinear behavior of the SRMS joints and the set of design tool utilized assuming linear behavior. The next design challenge is related to the positioning of the Orbiter by the SRMS determines the overall mated stacks inertia tensor properties. This impacts on how well the mated vehicles attitude motion generates secular Gravity gradient torques to oppose secular aerodynamic torques which can not be rejected by CMG torques. This makes the design goal of keeping small vehicle attitude variations and angular rates a difficult challenge under expected uncertainties.



A. CONTROLLER ARCHITECTURE

The controller architecture available in the ISS U.S. GN&C Flight software provides high level of flexibility to overcome many design issues to be encountered during the assembly of the ISS. This paper will be focusing specifically the architecture that supports non-propulsive attitude control. The actuators utilized are 4 double gimbaled CMGs. The linear controller is full state feedback controller which has access to the 9 controlled variables - attitude, attitude rate, and CMG momentum. The linear controller also utilizes the provided 3 integrators, 3 orbit frequency disturbance rejection filters, 3 twice orbit disturbance rejection filters all implemented in the LVLH frame [1]. Three 5^{th} Order filters are located in each of the axis of the angular vehicle rate signal for use in flex structure filtering. Also three 5^{th} Order filters are located in each of the axis of the Torque command coming from the linear rigid body controller for use in flex structure filtering. The rigid body gains and flex filter parameters are packaged in one uplinkable file. Thus having a unique flex filter for each set of rigid body gains does not complicate loading new MM designs into the ISS GN&C flight computer. Figure 2 shows a simplified closed loop diagram of the control system and linear flex body plant.